80 YEARS OF ELECTROSPINNING

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Abstract

Electrospinning is a relatively simple fibre-forming process and offers a unique method to produce nanofibers. The process exists at this moment 80 years and has seen a very turbulent history. There is a need to see what actually happened in this history. We have taken a brief look in the history of electrospinning. This paper is reporting on some of the aspects that electrospinning encountered. It is crucial to see that electrospinning has been used in different countries in different time periods. The history of electrospinning is mainly characterised by bad timing. The future of electrospinning looks however quit bright.

Keywords: Electrospinning, History

Introduction

Electrospinning is a relatively simple fibre-forming process and offers a unique method to produce nanofibers [1,2,3,4] from polymer solutions or melts. Electrospinning relies on electrostatic forces obtained by applying an electrical field by means of a DC voltage source between the tip of a nozzle and a collector. Once the electrostatic forces overcome the surface tension of the polymer solution at the nozzle tip a jet stream is drawn from the tip of the nozzle. The jet elongates while solvent is evaporating and the so produced nanofibers are deposited on the collector in the form of a random nonwoven structure. Electrospun nanofibers have interesting properties such as high specific surface area, high porosity and a high absorption capacity, which are useful properties for applications in filtration [5], sensors [6] and (bio)medicine [7].

The history of electrospinning is a rather complicated story. In the retro perspective of 80 years existence of the department of Textiles, another 80 years birthday occurs. Although the patent of Formhals is renewed on the 24th of March of 1934, the first application was in

Germany on the 7th of December of 1929. What happened since then is an issue that goes from zero to infinity.

In the beginning

Anton Formhals had a brilliant idea for a process to make silk-like fibers. Silk was quiet an expensive material in the beginning of the 20th century with some key applications like high end textiles. It was thus an interesting search to find a replacement material that was cheaper. Formhals based his idea actually on a finding on the knowledge that a dissolved solid in an electrical field will generate threads. His patent [1] however states that he has made a device that has the power to make the theoretical principle work in practice. Some drawings that he inserted in his patent can be seen in figure 1.

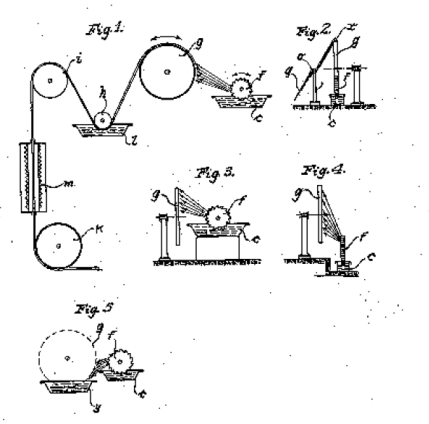

Figure 1: Schematic drawings by Formhals [1]

Clearly, Formhals had the power to make nanofibrous structures. In his patent he examples with cellulose acetate, a polymer that is still researched upon up to now. After the first application of the patent the 7th December of 1929, the global filing happened in October 1934. It was the right timing for a silk-replacer!

However, in the same time period, a lot of effort was put in the development of nylon. Carothers eventually discovered different nylons. The first one got patented in 1935. The output of electrospinning couldn't compete against the large-scale fiber spinning methods that were possible for nylon (and later polyester). Starting in world war II, nylon parachutes were used.

Entering the cold war

Electrospinning, as patented in the years '30, didn't had the output to compete with other techniques of that decade for some applications. However, since the electrospun nonwovens have some special properties, some special applications were sought and found.

Rozenblum and Petryanov-Sokolov were two Russian scientists working in the Karpov Institute in the former USSR. In 1938, they generated electrospun fibers for which they searched an application. Working from their background, which was in the Aerosol chemistry, they developed filter materials for the capturing of aerosols. This had it immediate use in protection issues in nuclear power plants. The filters were known as "Petryanov Filters".

The communistic government installed several factories starting from the years '40 in the USSR. In these factories, cellulose acetate was electrospun through a mixture of dichloroethane and ethanol. By the years '60, the output of spun filtration material in these factories was claimed as 20 million m^2 per year. Some of these factories still exist and still produce Petryanov filters [8].

There was no clear development in the Western world during the Cold War in the field of electrospinning. There is of course the theoretical work of Taylor in the years '60 that led to a mathematical model of electrospinning. The characteristic droplet shape of a fluid droplet in an electric field is still known as 'the Taylor cone'.

But there was no clear research going on in the Western world until the '90s of last century. Clearly, the non-governmental driven capitalistic industry didn't put their effort in the field of electrospinning. There is one exception though, that is the company Donaldson. They claim [9] that they developed their own electrospinning equipment in the '70s of the last century. With their process, they make enhanced air filters for the automotive industry.

Reinventing the wheel?

The first article in the Web of Science that takes the term 'electrospinning' into account appears in 1993 by the hand of Reneker. It is noted that the first couple of years only a couple of articles about electrospinning saw the daylight. The real boom in articles began around the year 2000, resulting in more than 3000 articles about electrospinning at present.

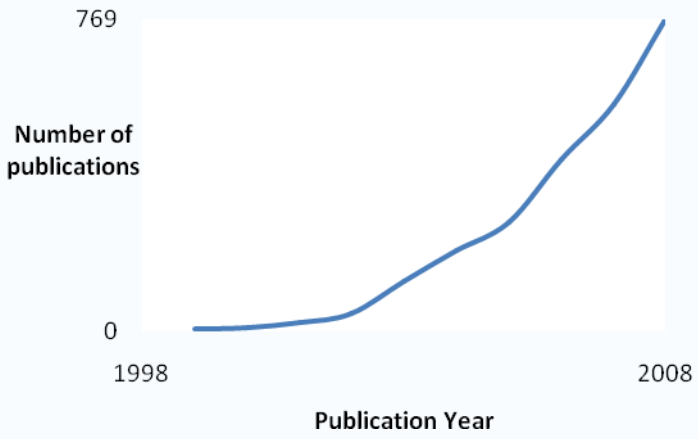

Figure 2: The number of publications about electrospinning is rapidly growing

Figure 2 shows that the number of publications about electrospinning is exponentially growing. Predictions for this year is that the curve will start to flatten. However, the number of publications is still enormously high and comparable to other hot topics in the field of science like stem cells or alternative energy sources.

It is only when the content is graded that another remark can be made with all these electrospinning articles. Most of the publications don't contribute to the field of electrospinning. They don't innovate the field, but repeat knowledge build up by other studies. This repetition is caused by the relative simplicity to build an electrospinning setup and to electrospin a polymer. The danger in this phenomenon is that there is no real progress in electrospinning with these publications. They reinvent the wheel.

Luckily, a part of the publications that sees the daylight does contribute to the progress in electrospinning. It is however difficult to really know what was already done in the past by secret laboratories in the USSR (or even in the US). So, perhaps there will be some rediscoveries done by modern science. These rediscoveries will however result in common and not in secret knowledge.

Conclusion

The history of electrospinning is mainly characterised by bad timing. The technique became only interesting in the same time period as the invention of the polyamides. After the second world war, electrospinning was further developed in the Cold War secret laboratories. This resulted in an industrialization in the USSR. It is only from the year 2000 on that a massive academic interest in the process results in common knowledge in electrospinning.

References

[1] Process and apparatus for preparing artificial threads. A Formhals US Patent. (1934) 1,975,504.

[2] Alginate-based nanofibers and related scaffolds. Z Miqin US Patent. (2007) WO2007112446

[3] Electrospinning of chitosan nanofibrous structures: feasibility study. S De Vrieze et al, Journal of materials science 42 (2007) 8029-8034

[4] Electrospinning of cellulose-based nanofibers. A Frenot et al, Journal of applied polymer science 103 (2007) 1473-1482

[5] Electrospun fibre mats: transport properties. PW Gibson et al, AICHE J 45 (1999) 190-195

[6] Electrospun polymer nanofibre sensors. D Aussawasathien, JH Dong, L Dai, Synthetic Metals 154 (2005) 37-40

[7] A study on the preparation of poly(vinyl alcohol) nanofibers containing silver nanoparticles. WJ Jin et al, Synthetic Metals 157 (2007) 454-459

[8] www.sorbent.su
www.ehmz.ru

[9] www.donaldson.com